Smart Sensor Interface Standards IEEE 1451.0 and 1451.5

Net-Ready Sensors Workshop

August 2-3, 2006
Oak Ridge, Tennessee

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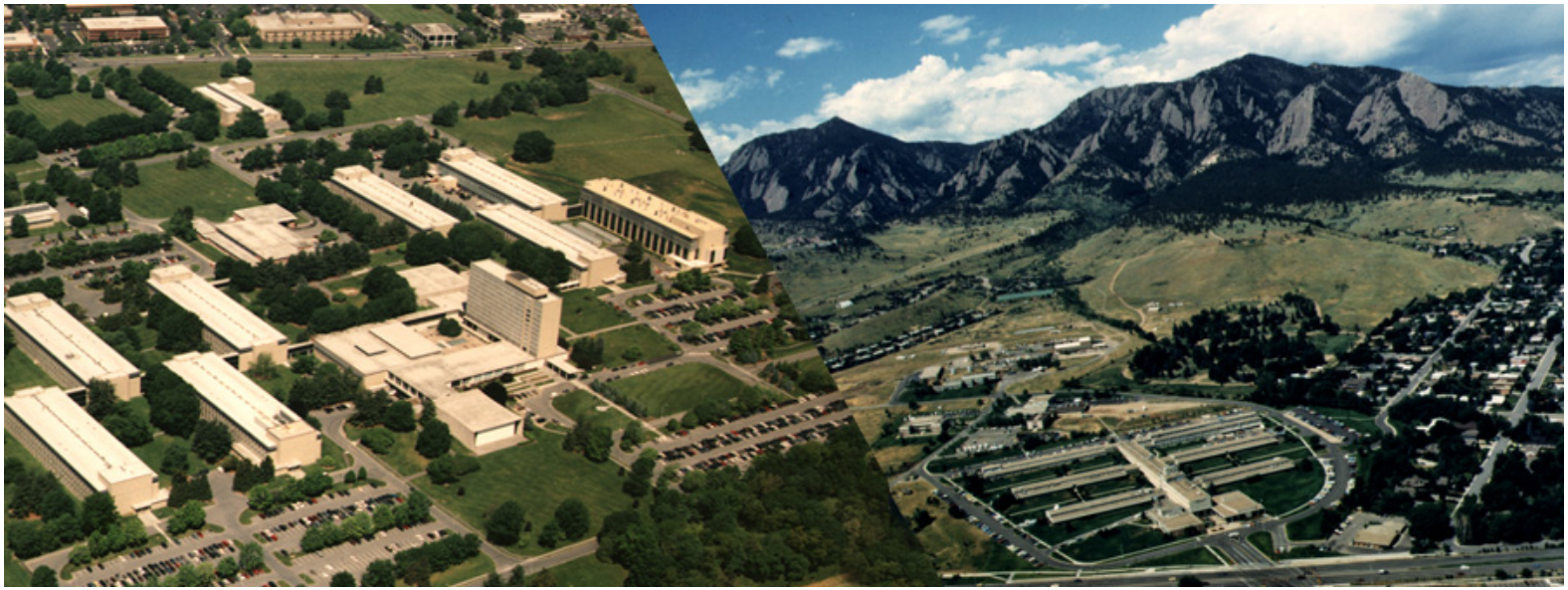
Outline

- **IEEE 1451 Smart Transducer Interface Standard**
- **IEEE 1451.0**
- **IEEE 1451.5**
- **Sensor Standards Harmonization Effort**

National Institute of Standards and Technology (NIST)

Mission: Develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.



Gaithersburg, Maryland

Boulder, Colorado

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Why Sensor Standards ?

- Sensors and networks are key components in building distributed sensor networks nation-wide for detecting weapons of mass destruction and monitoring and protecting critical infrastructure such as airports, bridges, buildings, railways, utility, water supplies, and the nation's border.

- Tens of thousands of sensors will be connected through wired and wireless networks for communicating and sharing sensor data and information among government agencies and private enterprises in order to effectively protect people and property.

- Open, standardized sensor interfaces and sensor data formats are needed to enable effective integration, access, fusion, and use of sensor-derived data in critical homeland security (HLS) applications.

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Current Trends

- Fast moving toward using networked, digital, and wireless communications for sensors
  - U.S. Navy planning to use thousands of networked, wireless sensors in ships to reduce manning, enhance automation, and condition-based maintenance.
  - Airplane manufacturers moving to use networked, wireless systems for sensor connectivity to lower life cycle costs.
  - Homeland security applications moving to use networked, wireless sensor systems for remote monitoring and situation awareness.
- All these applications are seeking open standard solutions.

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From a User's Perspective

- As a user, wouldn't you like to pick up a sensor and use it without doing a lot of extra preparatory work?
  - You acquire a sensor from a vendor based on merit.
  - You simply plug the sensor into a system or network.
  - The sensor identifies itself to the system or network.
  - The sensor sends data to describe itself to the system or network.
  - Based on the data, the system can automatically configure for sensor integration.
  - All these functions are done with no or minimal human interference, which could potentially introduce errors.
  - Now the sensor is ready to be used.

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That is what IEEE 1451 is all about

It provides standard ways to connect sensors and actuators to networks and systems, with the aim to facilitate

"Interoperability"

At the SensorGov Conference on Sept 13-14, 2004.

Dr. Vitalij Garber, Director of Systems Integration, Defense System,

Office of Under Secretary of Defense, said,

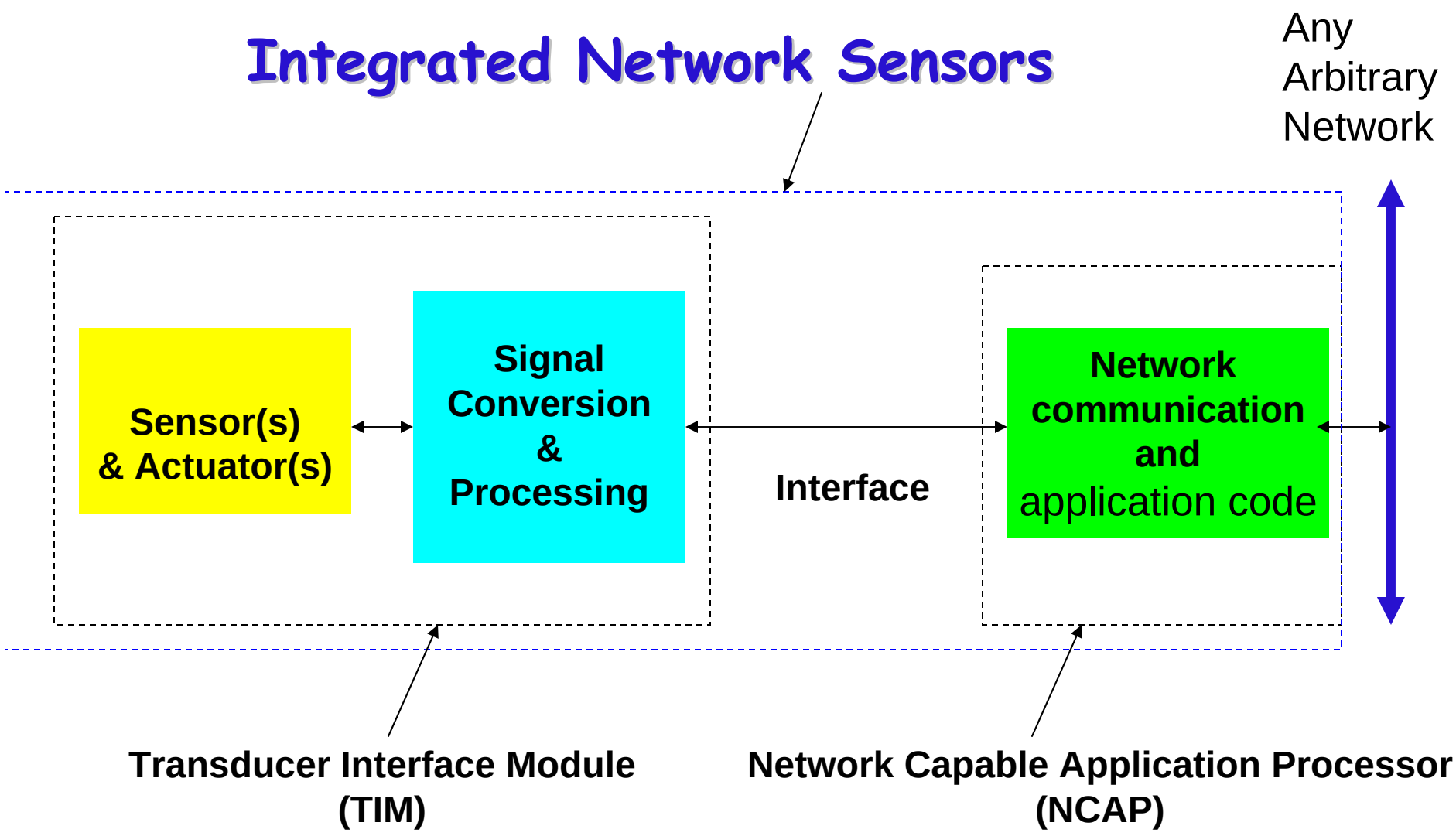
"…from sensors perspective, let's tie them together for interoperability by FY08. Anything that is not integrated, leave it out.

…net all sensors and provide seamless operation.

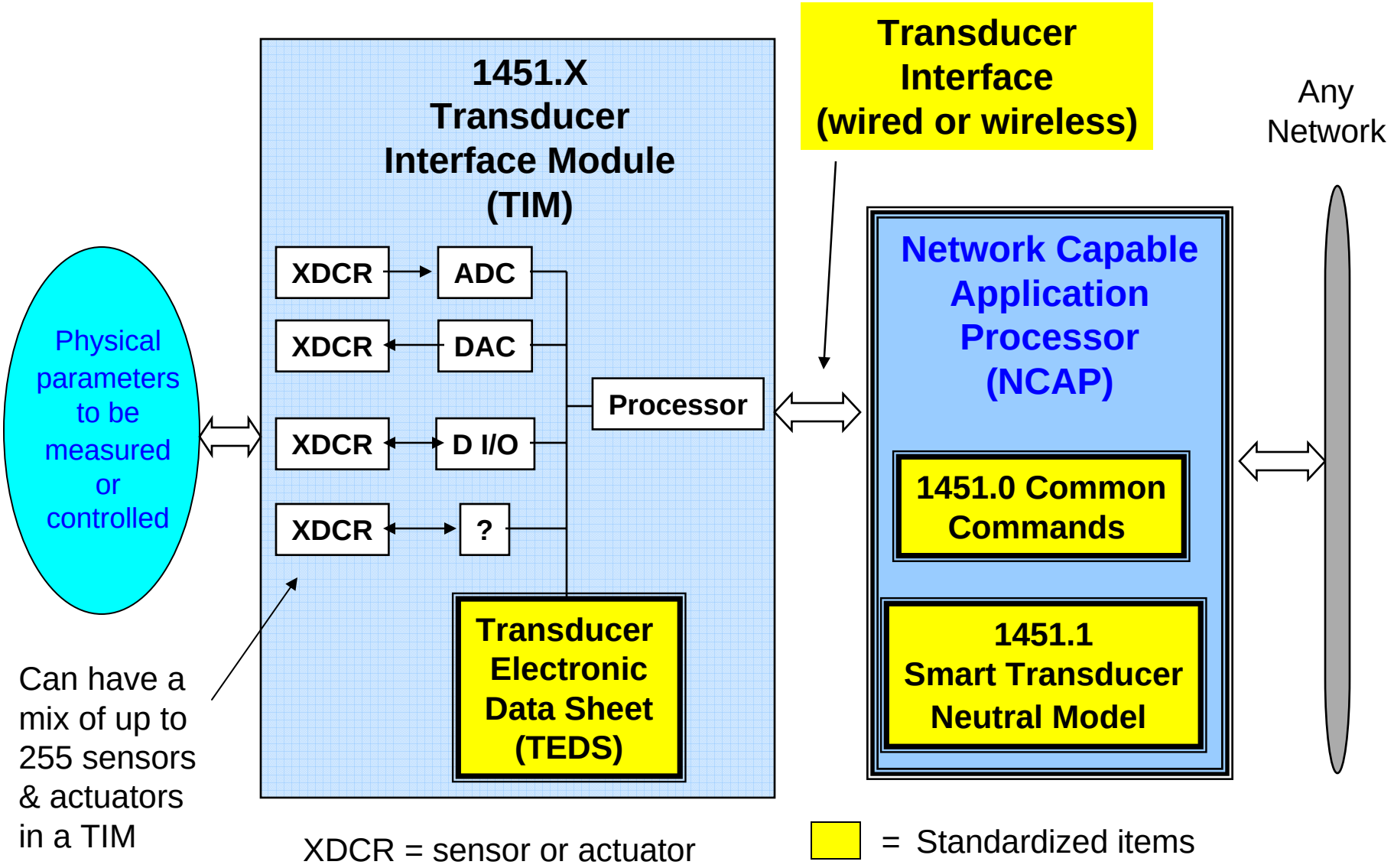
… maximum use of commercial standards and approach."

This resonates with the heart of the subject matter of this workshop "Net-Ready Sensors".

Integrated Network Sensors



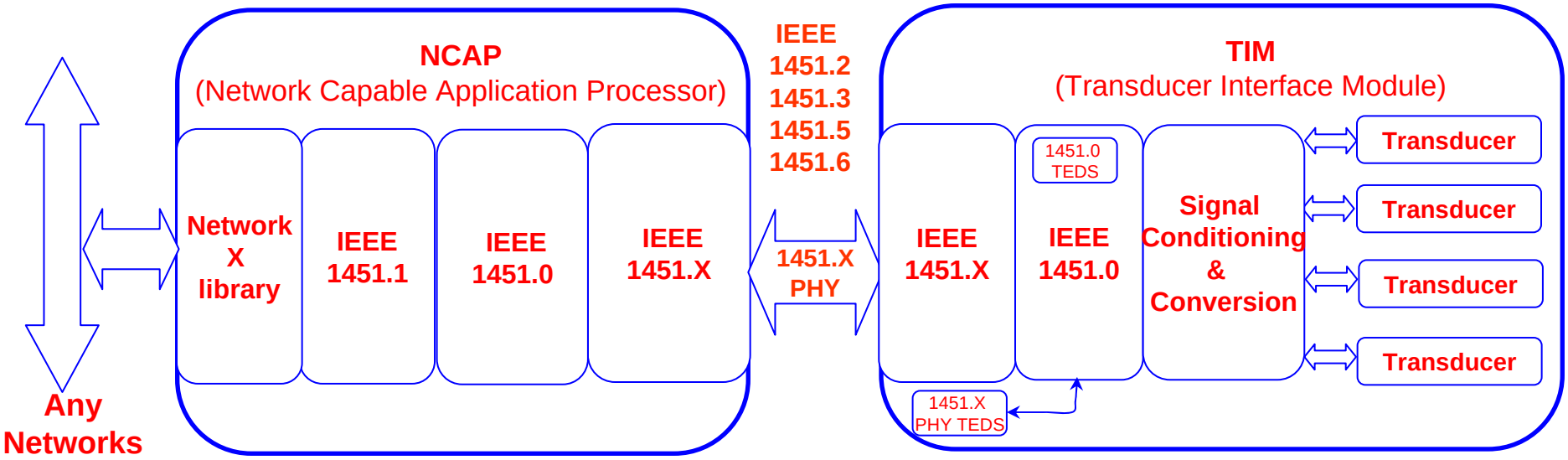
IEEE 1451 Networked Smart Transducers Diagram



So what is IEEE 1451 ?

IEEE 1451, a suite of Smart Transducer Interface Standards, describes a set of open, network-independent communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems, and networks.

The key feature of these standards is the definition of Transducer Electronic Data Sheets (TEDS) that stores transducer identification, calibration, correction data, measurement range, and manufacture-related information, etc. TEDS are paper sensor data sheets in electronic form.



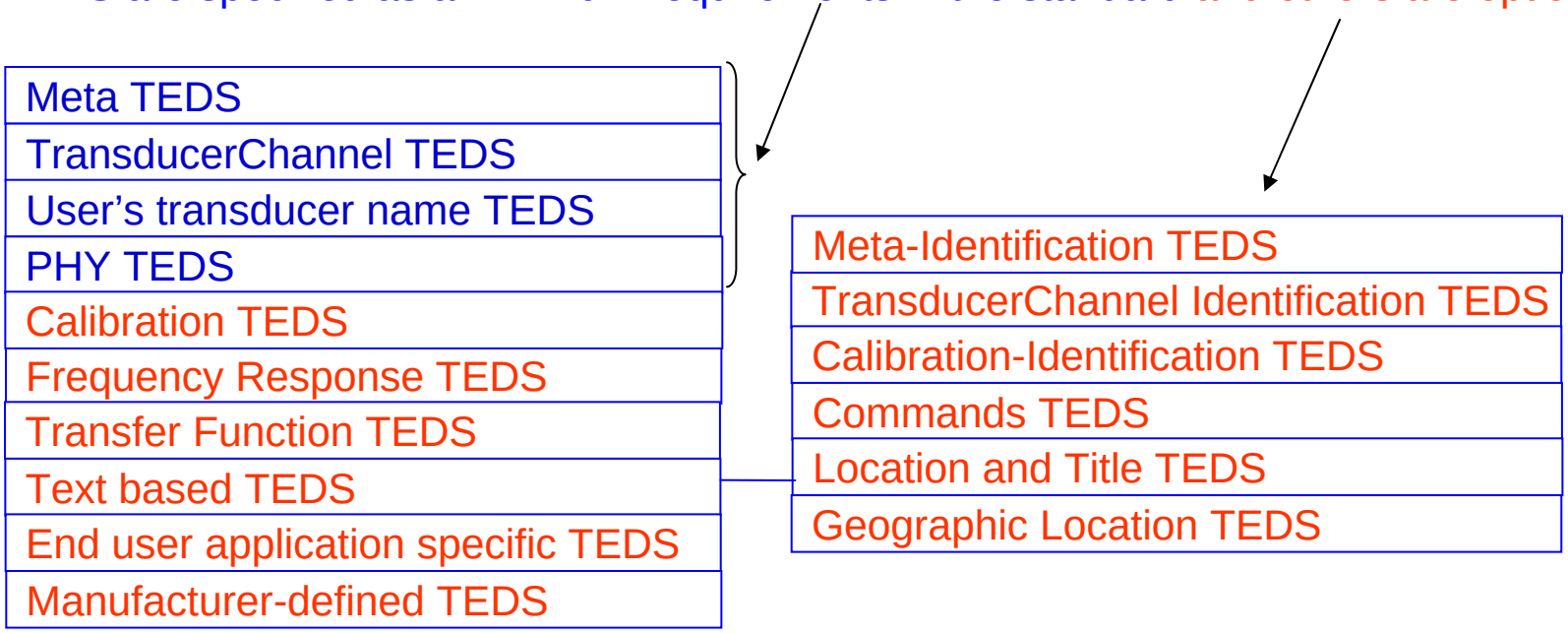
IEEE 1451.0
Transducer Electronic Data Sheets (TEDS)

• The IEEE 1451.0 TEDS are used to describe the entire TIM which includes the transducer (sensor and actuator), signal conditioner, and data converter.

• The TEDS is a memory device attached to the transducer, which stores transducer identification, calibration, correction data, measurement range, and manufacture-related information, etc.

• TEDS includes all kinds of transducer data and it can be viewed as a transducer data model

• Four TEDS are specified as a minimum requirements in the standard and others are optional



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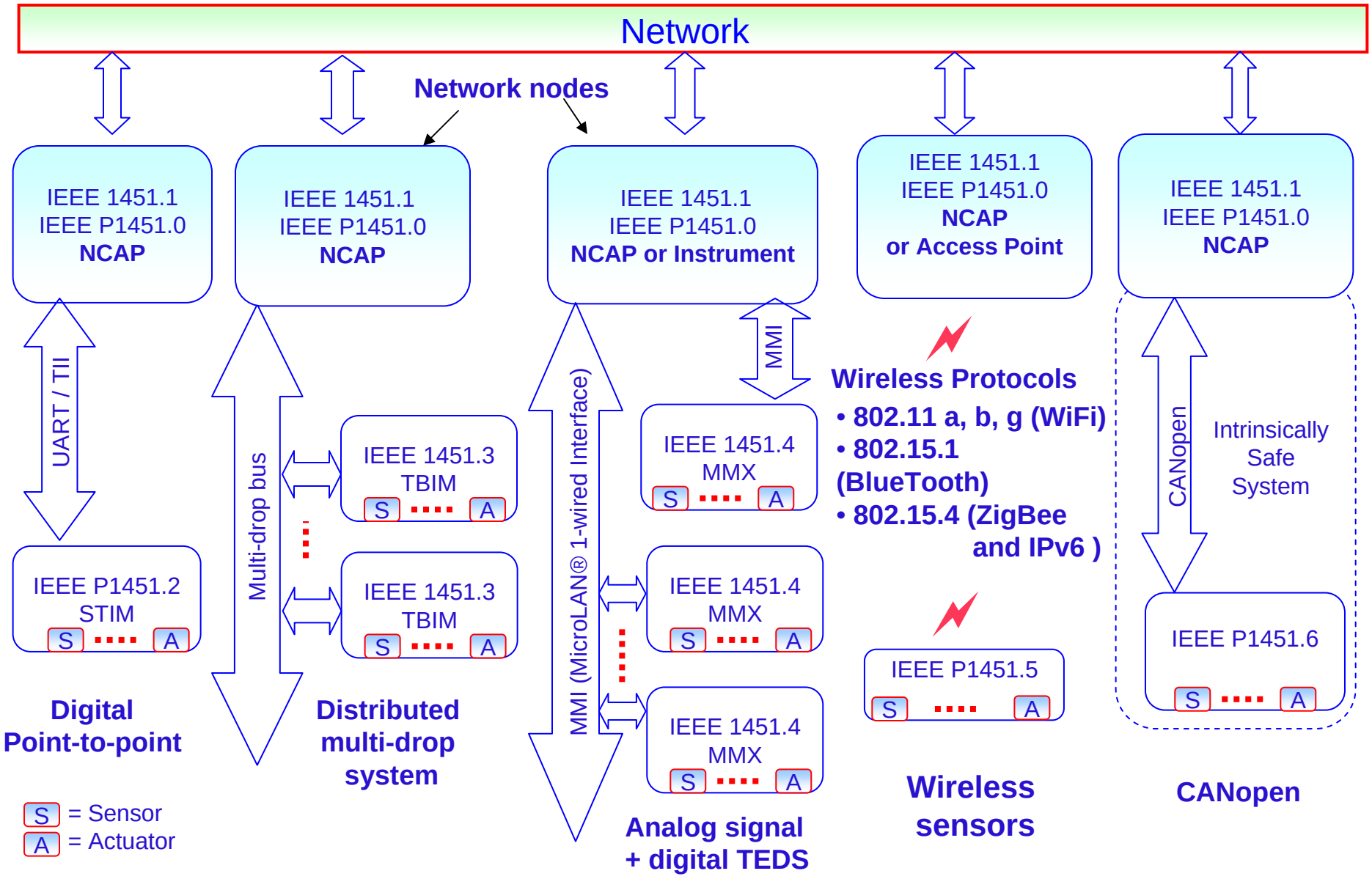
Goals of IEEE 1451 Smart Transducer Standards

- Develop network-independent and vendor-independent transducer interfaces
- Define standardized Transducer Electronic Data Sheets (TEDS) that contain manufacture-related data (replace paper printed data sheet)
- Support a general model for transducer data, control, timing, configuration, and calibration,
- With TEDS, it virtually eliminates error prone, manual entering of data and system configuration steps,
- Allow transducers (sensors or actuators) to be installed, upgraded, replaced, or moved by simply plug-and-play that requires low-level technical support,
- Enable the access of sensor data in wired or wireless networks and systems.
- Provides an infrastructure for open-system distributed architecture.

IEEE 1451 Suite of Standards



Status of the IEEE 1451 Standards

- **IEEE Std 1451.1-1999,** Network Capable Application Processor (NCAP) Information Model for smart transducers -- *Published standard, to be revised*

- **IEEE P1451.0,** Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats -- *In balloting*

Physical layers

- **IEEE Std 1451.2-1997,** Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats -- *Published standard, being revised*
- **IEEE Std 1451.3-2003,** Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems -- *Published standard*
- **IEEE Std 1451.4-2004,** Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats – *Published standard*
- **IEEE P1451.5,** Wireless Sensor Communication and Transducer Electronic Data Sheet (TEDS) Formats – *In balloting*
- **IEEE P1451.6,** A High-speed CANopen-based Transducer Network Interface – *In progress*

IEEE P1451.0 Standard

IEEE 1451.0 is a proposed standard for a smart transducer interface for sensor and actuators – functions, communication protocols, and transducer electronic data sheet (TEDS) formats.

IEEE 1451.0 standard provides a functional specification for transducer interface module (TIM), message exchange protocols, a set of commands defined to facilitate the set up and control of the transducer modules, and TEDS definition and management, interface protocols with P1451.0 and 1451.X, discovery and management of TIMs.

TransducerServices based on IEEE 1451.0 API
The API contains interfaces for discovering registered TIMS, accessing TransducerChannels to make measurements or write actuators, managing TIM access, and reading and writing TEDS.

IEEE 1451.0:TransducerService

IEEE1451dot0::TransducerServices::TimDiscovery
Args::UInt16 reportCommModule(out Args::UInt8Array moduleIds);
Args::UInt16 reportTims(in Args::UInt8 moduleId, out Args::UInt16Array timIds);
Args::UInt16 reportChannels(in Args::UInt16 timId, out Args::UInt16Array channelIds, out Args::StringArray names);
Args::UInt16 getCommModule(in Args::UInt8 moduleId, out ModuleCommunication::Comm commObject, out Args::UInt8 type, out Args::UInt8 technologyId);

IEEE1451dot0::TransducerServices::TransducerAccess
Args::UInt16 open(in Args::UInt16 timId, in Args::UInt16 channelId, out Args::UInt16 transCommId);
Args::UInt16 openQoS(in Args::UInt16 timId, in Args::UInt16 channelId, inout Args::QoSParams qosParams, out Args::UInt16 transCommId);
Args::UInt16 openGroup(in Args::UInt16Array timIds, in Args::UInt16Array channelIds, out Args::UInt16 transCommId);
Args::UInt16 openGroupQoS(in Args::UInt16Array timIds, in Args::UInt16Array channelIds, inout Args::QoSParams qosParams, out Args::UInt16 transCommId);
Args::UInt16 close(in Args::UInt16 transCommId);
Args::UInt16 read(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 SamplingMode, out Args::ArgumentArray result);
Args::UInt16 write(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 SamplingMode, in Args::ArgumentArray value);
Args::UInt16 startRead(in Args::UInt16 transCommId, in Args::TimeInstance triggerTime, in Args::TimeDuration timeout, in Args::UInt8 SamplingMode, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 startWrite(in Args::UInt16 transCommId, in Args::TimeInstance triggerTime, in Args::TimeDuration timeout, in Args::UInt8 SamplingMode, in Args::ArgumentArray value, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 startStream(in Args::UInt16 transCommId, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 cancel(in Args::UInt16 operationId);

IEEE 1451.0:TransducerService

Ieee1451Dot0::TransducerServices::TedsManager
Args::UInt16 readTeds(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 tedsType, out Args::ArgumentArray teds);
Args::UInt16 writeTeds(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 tedsType, in Args::ArgumentArray teds);
Args::UInt16 readRawTeds(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 tedsType, out Args::OctetArray rawTeds);
Args::UInt16 writeRawTeds(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 tedsType, in Args::OctetArray rawTeds);
Args::UInt16 updateTedsCache(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 tedsType);

Ieee1451dot0::TransducerServices::TransducerManager
Args::UInt16 lock(in Args::UInt16 transCommId, in Args::TimeDuration timeout);
Args::UInt16 unlock(in Args::UInt16 transCommId);
Args::UInt16 reportLocks(out Args::UInt16Array transCommIds);
Args::UInt16 breakLock(in Args::UInt16 transCommId);
Args::UInt16 sendCommand(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt8 cmdClassId, in Args::UInt8 cmdFunctionId, in Args::ArgumentArray inArgs, out Args::ArgumentArray outArgs);
Args::UInt16 startCommand(in Args::UInt16 transCommId, in Args::TimeInstance triggerTime, in Args::TimeDuration timeout, in Args::UInt8 cmdClassId, in Args::UInt8 cmdFunctionId, in Args::ArgumentArray inArgs, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 configureAttributes(in Args::UInt16 transCommId, in Args::StringArray attributeNames);
Args::UInt16 trigger(in Args::UInt16 transCommId, in Args::TimeInstance triggerTime, in Args::TimeDuration timeout, in Args::UInt16 SamplingMode);
Args::UInt16 startTrigger(in Args::UInt16 transCommId, in Args::TimeInstance triggerTime, in Args::TimeDuration timeout, in Args::UInt16 SamplingMode, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 clear(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in Args::UInt16 clearMode);
Args::UInt16 registerStatusChange(in Args::UInt16 transCommId, in Args::TimeDuration timeout, in AppCallback callback, out Args::UInt16 operationId);
Args::UInt16 unregisterStatusChange(in Args::UInt16 transCommId);

Sensor Web Services based on IEEE 1451

Proposed Sensor web services based on IEEE 1451.0 transducer services:

TimDiscoveryServices:

- reportTims(timIds)
- reportSensors(timId, channelIds, sensorNames)

SensorObservationServices:

- readSensorData (tim_id, channel_id, timeout, sampleMode, ArgumentArray result)
- writeSensorData (tim_id, channel_id, timeout, sampleMode, value)

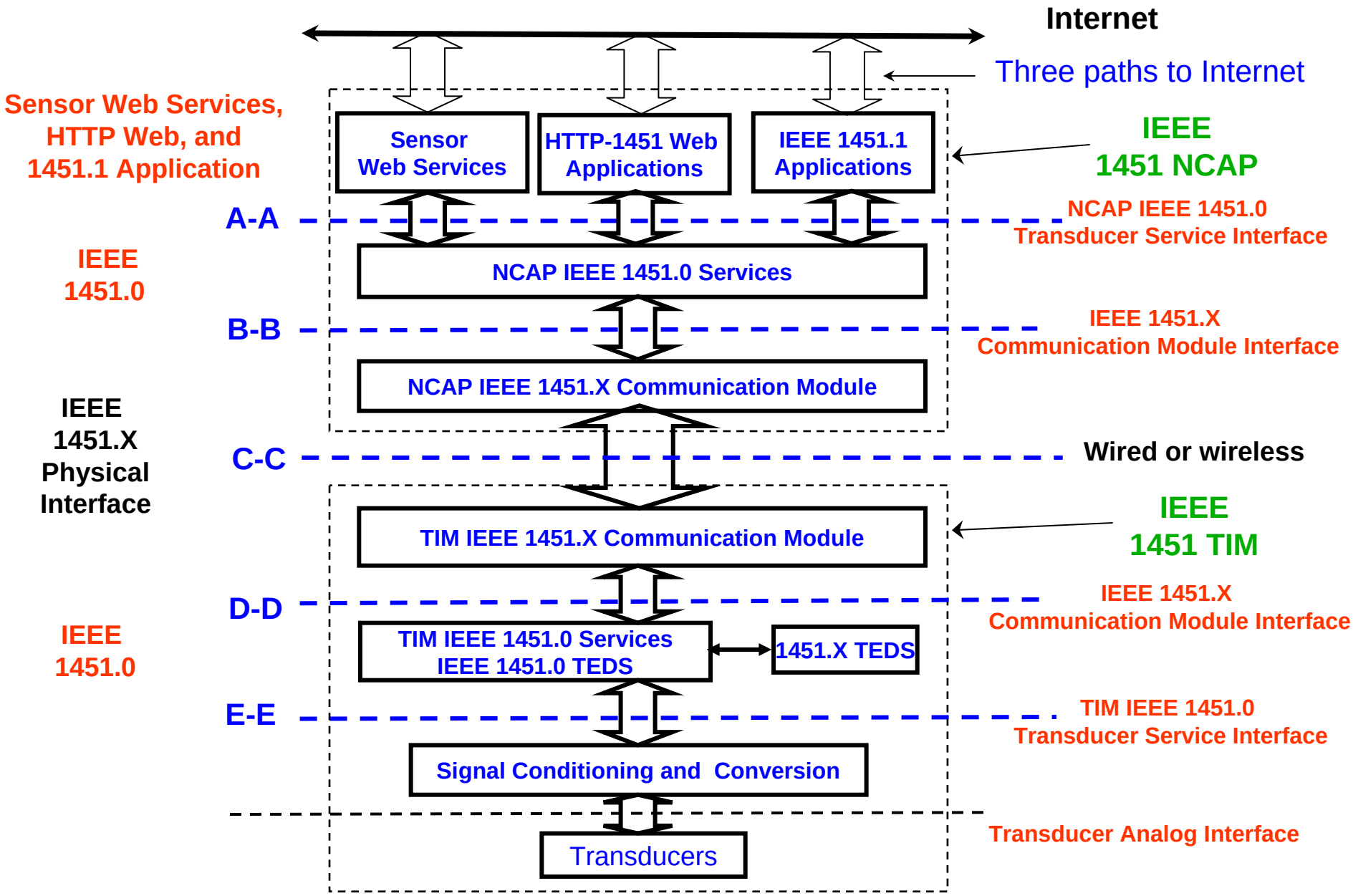
SensorTEDSServices:

- readSensorTEDS (tim_id, tedsType, timeout, sampleMode, ArgumentArray result)
- writeSensorTEDS (tim_id, tedsType, timeout, sampleMode, ArgumentArray value)

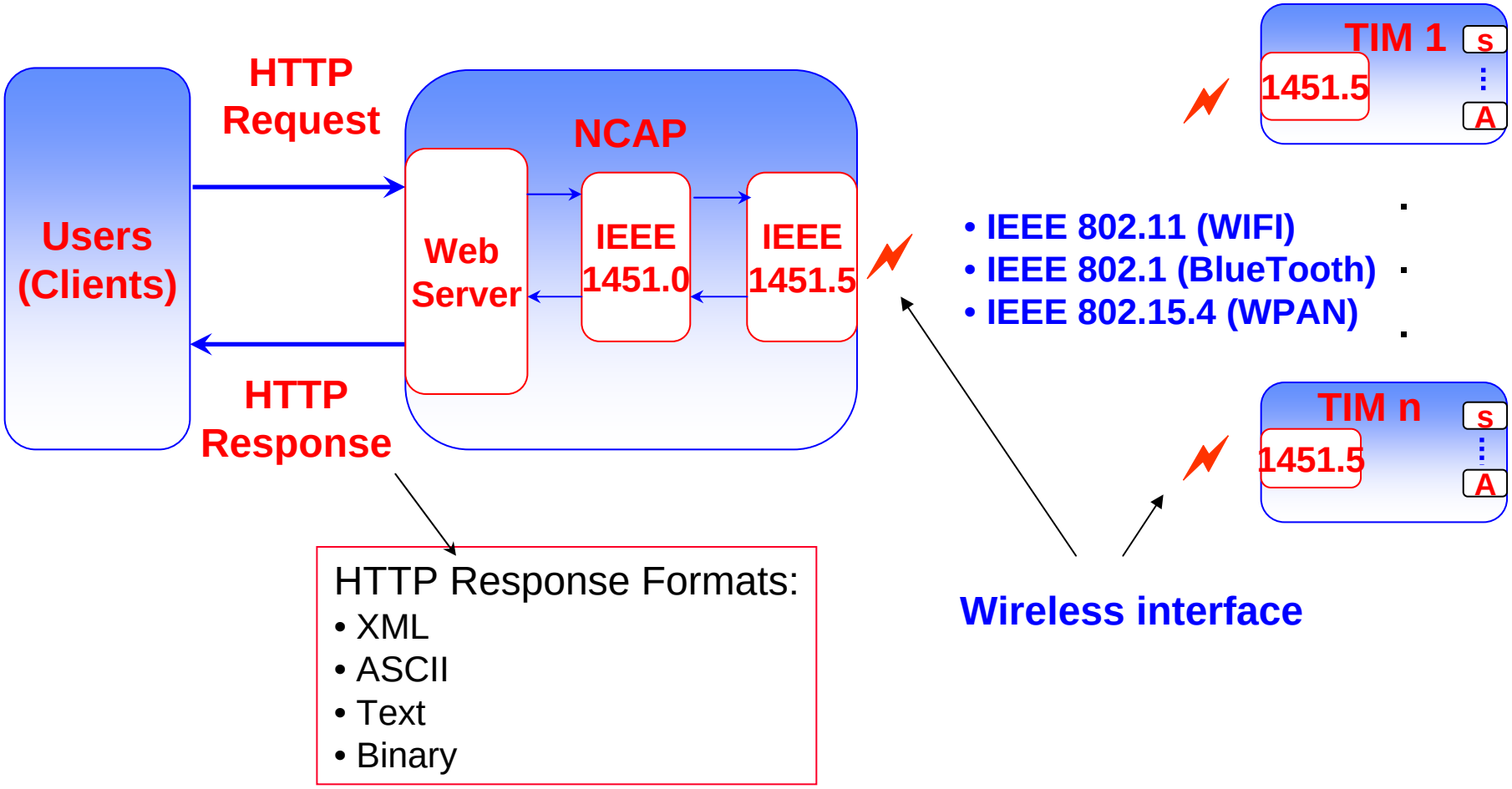
IEEE 1451.0 Provides Common Functions to IEEE 1451.x

- Hot Swap Capability
- Status Reporting
- Self-Test Capability
- Service Request Messaging
- Synchronous Data Acquisition from Arrays of Sensors
- Streaming Data Mode

IEEE 1451 Stack



IEEE 1451 HTTP Web Application Integrating IEEE 1451.0 and 1451.5 Standards



IEEE 1451 HTTP Request: Examples

- **ReadSensorData:**

```
GET (timId, transducerId, timeDuration, sampling Code,
outputFormat)
```

- **ReportSensorAlert:**

```
GET (timId, transducerId, descendingThreshhold
ascendingThreshhold, outputFormat)
```

- **ReportSensorAlert:**

```
GET (timId, transducerId, timeDuration, samplingCode,
outputFormat)
```

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IEEE 1451 HTTP API Summary

Discovery API	•**TIMDiscovery** •**TransducerDiscovery**
Transducer Access API (Read & Write)	•**Read** •**StartRead** •**StartStream** •**Write** •**StartWrite**
Sensor Alert API	•**SetSensorAlert** •**ReportSensorAlert**
TEDS Manager API	•**ReadTeds** •**ReadRawTeds** •**WriteTeds** •**WriteRawTeds** •**UpdateTedsCache**
Transducer Manager API	•**SendCommand** •**StartCommand** •**Trigger** •**StartTrigger**

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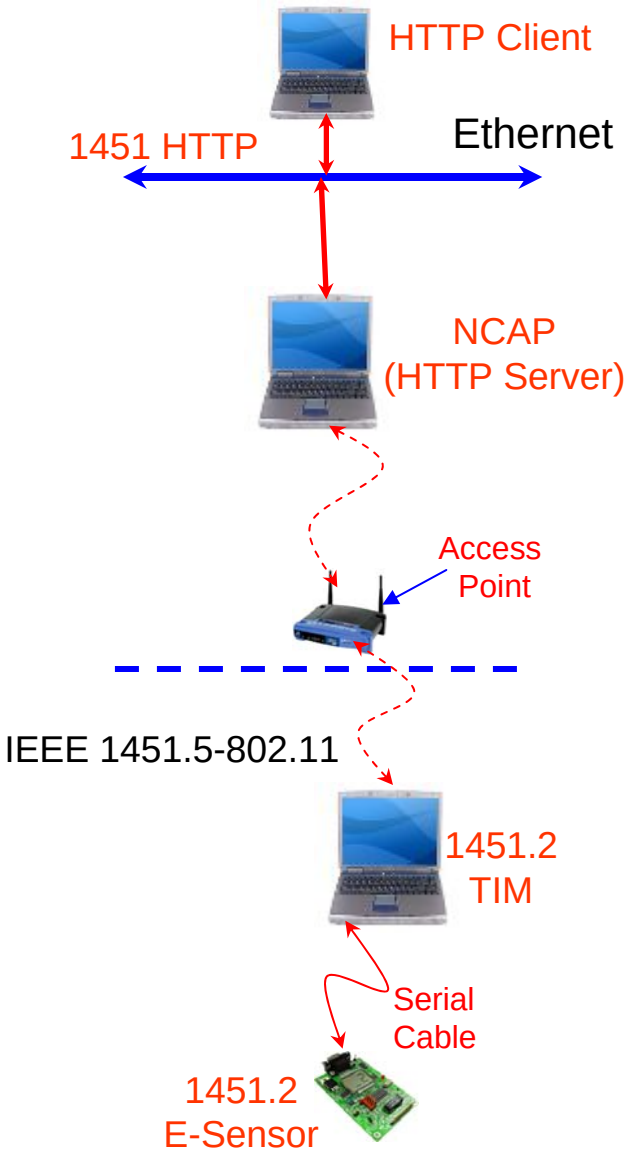
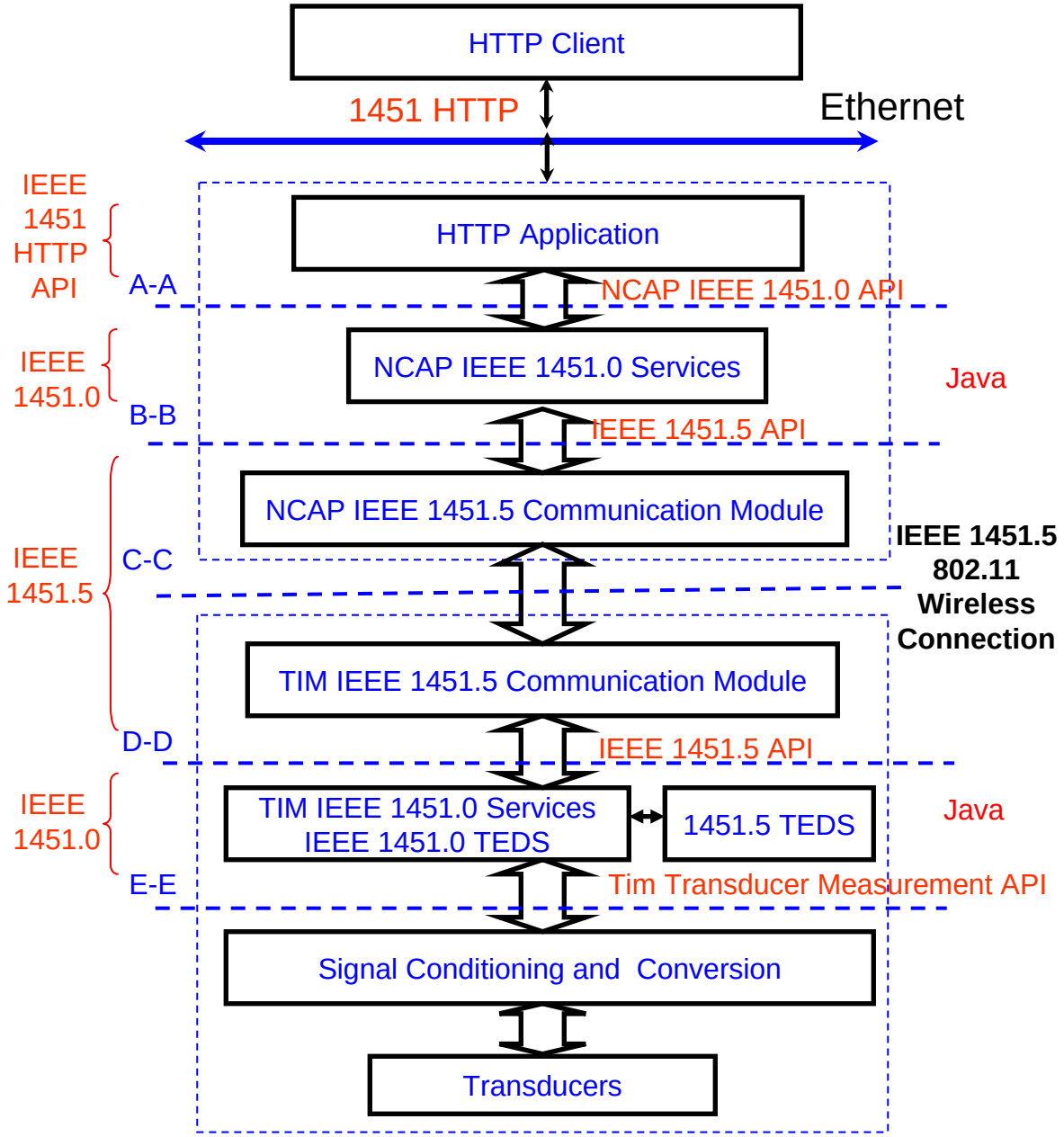
IEEE 1451.5 Wireless Sensor Standard

- The working group has decided to include multiple PHY and MAC standard wireless protocols in the proposed IEEE 1451.5 standard
  - IEEE 802.11 / Wi-Fi
  - IEEE 802.15.1 / Bluetooth
  - IEEE 802.15.4 / ZigBee
  - IEEE 802.15.4 / IPv6

- Each PHY / MAC combination provides a higher layer API interface for seamless interoperability with IEEE 1451.0
- WiFi, ZigBee, and Bluetooth have there own native ways of handling security and key exchange

A Reference Implementation of IEEE 1451 HTTP Web Application





Benefits using IEEE 1451

Sensor manufacturers

- Standard interfaces
- Multiple products may be developed just by changing the TEDS.
- Standard calibration specification

System integrators

- Self-documenting hardware and software
- Systems that are easier to maintain
- Rapid transducer replacement
- Mechanism to store installation details

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Benefits using IEEE 1451 - cont'd

Application software programmers

- Standard transducer model for control and data
- Same model for accessing a wide variety of measurements
- "Hooks" for synchronization, exceptions, simultaneous sampling
- Support for multiple languages

End users

- Sensors that are easier to use; "you just plug them in".
- Analysis software that can automatically provide:
  - physical units
  - readings with significant digits
  - transducer specifications
  - installation details such as physical location and ID of transducer

Sensor Standards Harmonization (SSH) Working Group

- **Purposes**
  - Provide a forum for industry, academia, and government to exchange information and improve understanding of the various sensor-related standards programs being advanced by various standards development organizations,
  - Identify opportunities to frame the harmonization of sensor-related standards to meet the need of the community,
  - NIST agreed to lead the effort and organize quarterly working group meeting at NIST on the third Tuesday of the month starting December 2005.
  - Next meeting is 9/12/06.

Some Harmonization Issues and Opportunities (1)

- **A common sensor protocol should be able to handle a wide range of conops and use cases.**

- **Uses cases**
  - **DHS has published 15 scenarios from which use cases can be derived. This work should be considered as a resource for standards organizations to jointly develop test and validate sensor standards.**
  - **Sponsors of sensor standards work should consider supplying a concise, consistent set of use cases to standards to facilitate standards harmonization**
  - **Standards organizations are using use cases now, but a common set will encouage further convergence.**

- **Sensor data and information Sharing**
  - **How will data be shared?**
  - **Will data be available to those who need it (regardless of security clearance level)?**
  - **Disconnection between state/local/regional and federal data systems.**
  - **Jurisdictional security is an issue; it is under review.**

Some Harmonization Issues and Opportunities (2)

- Joint Testbeds **(e.g. IEEE 1451, OASIS, OGC) need to be developed, and implemented to accelerate standards development, facilitate joint testing and validation, and identify gaps. Funding should be identified to leverage near term testbed activities.**
- **Interoperability demonstrations are a way to show that system is functional – from lower level sensor network to higher level application layer.**
- **Government should** specify relevant sensor standards in procurements**. This will accelerate market provision of plug-and-play systems, which will lower maintenance costs and allow for easier upgrades than proprietary systems.**
- **Government should** encourage standards organizations to collaborate **on advancement of sensor and related standards based frameworks needed to meet mission needs.**
- **Provide cooperating standards organizations with a common set of use cases, along with access to sensor assets for testing and prototyping. The need is imminent, and quick examples of urgent use cases are necessary.**

Some Harmonization Issues and Opportunities (3)

- The Sensor Standards Harmonization Working Group will come to agreement on initial set of standards to articulate to government and industry.
- Gap analysis:
  - Consistent, accurate methodology for defining “location” in content objects of EDXL payload (OGC standards may offer the solution)
  - Based on results from joint testbed activities, affirm standards capability and identify gaps for further work (e.g. prioritization/tasking of sensors/actuators)
  - Two sets of sensor standards are needed:
    - Within sensor systems (IEEE 1451)
    - Between sensor systems (OASIS and OGC offer standards solutions for this environment)
- Actions:
  - Conference call to discuss next major testbed, a convergence of geospatial building of information models, emergency management, OGC Sensor Web Enablement, CAP, EDXL, CBRN data model, and IEEE 1451.

Sensor Standards Harmonization Effort helps to educate government to use standards in procurement specification

- Through participation in the SSH meetings,

  U .S. Department of Homeland Security Domestic Nuclear Detection Office (DNDO) participants learned about various sensor related standards and their relationships.

- Recently DNDO has defined a set of specification,

  “PERFORMANCE SPECIFICATION FOR HUMAN PORTABLE RADIATION DETECTION SYSTEM (HPRDS)”

Excerpts of HPRDS Specification

- ***6.3 User Interface***
- *6.3.1 Command and Control*
  - j. Handheld and Wearable HPRDSs shall provide gamma spectra for off-line analysis by a separate program in a format specified by ANSI Standard N42.42.

- *6.3.3 Communications Interface*
  - h. The Handheld and Wearable HPRDS sensor discovery and data transfer shall use an open standard service discovery protocol such as IEEE 1451, Universal Plug N Play (UPNP), or Jini. The preferred protocol is IEEE 1451.0.

- ***6.6 Interconnectivity***
  - c. Handheld and Wearable HPRDSs shall be able to interface and deliver electronic formatted data to the “Reachback” location using a standard data format in compliance with ANSI Standard N42.42.

For More Information

- **Contact: Kang Lee at kang.lee@nist.gov, 301-975-6604**
- **IEEE standards can be purchased at http:// ieee.org**
- **IEEE 1451 websites:**
  - **1451: http://ieee1451.nist.gov**
  - **1451.4: http://grouper.ieee.org/groups/1451/4**
  - **1451.5: http://grouper.ieee.org/groups/1451/5**
  - **1451.6: http://grouper.ieee.org/groups/1451/6**
- **IEEE 1588 website: http://ieee1588.nist.gov,** Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems